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Effect of grading and lime content on HMA stripping using statistical methodology

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ABSTRACT

Response surface methodology was employed to evaluate the effect of lime content and grading on the dry and saturated indirect tensile strength as well as Tensile Strength Ratio of hot mix asphalt. The statistical significance of linear, quadratic and interactive terms of these factors were examined and second order polynomial models were successfully fitted to the experiment data. It was shown that maximum Tensile Strength Ratio was achieved at 1% lime content and with grading containing most coarse aggregate. It was further concluded that decreasing the aggregate size and increase in mastic asphalt would increase the stripping potential of hot mixes asphalt.

1. Introduction

Stripping, a failure recognized since the advent of asphalt paving technology [1], is among the most important failure modes of asphalt mixtures which could make the pavement layers prone to other types of failure such as rutting and cracking [2]. In presence of moisture as well as traffic loading, two events can occur; the loss of adhesive bond between the asphalt and aggregate (a failure of the bonding of asphalt to aggregate) and/or softening of the cohesive bonds within the asphalt (a failure within the asphalt itself) [1]. It should be pointed out that stripping phenomenon not only results in poor pavement performance but also leads to higher maintenance cost [3,4].

National Cooperative Highway Research Program (NCHRP) carried out a comprehensive investigation in 1991 on moisture damage in Hot Mix Asphalt (HMA) [5]. Many other researchers have also studied the moisture damage since that report [1,2,6,7].

Researchers have used different types of tests to evaluate moisture sensitivity of asphalt mixtures [2,8–12], but it seems that there is no general consensus among researchers on a single method for evaluating this distress [2]. Among the numerous conventional test procedures, such as boiling test, Marshall and indirect tensile tests, some researchers and institutions [13–17] believe that the later is more capable of predicting stripping phenomenon.

Characteristics of HMA depend on physical and mechanical properties of the constituent materials and its production technology [3,6,18]. Two of the pertinent factors, which influence the stripping characteristics of HMA, are the aggregate grading and the type and amount of the anti stripping agent such as lime [19]. Thus, the appropriate selection of particle size as well as the amount of anti-stripping agents (lime) in HMA mixture can improve the structural and mechanical properties of asphalt concrete pavement [18].

The addition of hydrated lime – as an anti-stripping additive – results in increasing HMA stiffness, fracture toughness and oxidation protection as well as decreasing rutting, fatigue and cracking deformation [5,7,20,21]. The main role of hydrated lime is to convert a hydrophilic aggregate surface to a hydrophobic aggregate [3,4]. Furthermore, it has been reported that hydrated lime, apart from the other mixture constituents, plays a major role in improving the stripping resistivity of HMA [5,20].

Abo-Qudais and Al-Shweily investigated the effect of anti-stripping additives, aggregate grading, and type of asphalt on the HMA environmental damage and creep behavior. They found that the aggregate grading, asphalt type, and the type of anti-stripping additive have a significant effect on creep deformation and environmental damage [4]. In addition, Abo-Qudais and Mulqi reported that using calcium stearate hydroxide reduces environmental damage in asphalt mixes consisting of limestone and basalt aggregate [22].

A literature review on the influential parameters in HMA stripping characteristics provides no clues to the existence of any interactions between important parameters. This is because in previous studies one-factor-at-a-time methodology has been used

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to optimize and evaluate the parameters. This methodology is very inefficient and furthermore gives absolutely no information about interactions between parameters. The only methodology capable of providing an answer to this question is factorial Design of Experiments (DOE), which – through the use of techniques such as Response Surface Methodology (RSM) – is able to simultaneously consider several factors at different levels, and give a suitable model for the relationship between the various factors and the response. However, it seems that RSM has not been used to investigate the combining effects of lime and grading on moisture damage.

Among the two factorial designs, full and fractional; the former gives the most complete information regarding interaction between parameters but the number of experiments becomes excessive when the number of factors or their levels becomes relatively large. Additionally, higher order interactions, obtained in full factorial, are usually statistically insignificant and, consequently, information about them is not very useful [23]. Fractional factorial designs (FFD) – such as central composite design (CCD) or Box–Behnken – can give information regarding parameter interactions with the use of less experimentation; however, reliable information about first order interactions can only be obtained from the results of DOEs which are not highly fractionated [23].

The aim of the present work was to examine the effect of grading and lime content on stripping potential of HMA, as well as interactions between them, using appropriate methodology, namely RSM. A half fractional factorial CCD was chosen as the design matrix since it allows reliable identification of first order interaction between factors and provides a second order polynomial model, which can be used to predict optimum level of these parameters.

2. Materials and methods

2.1. Materials

In the present work, dense grading aggregates including three levels of dense aggregates, i.e. fine, medium and coarse grading (denoted as D1, D2 and D3) were selected. These were based on the average values of three of the typical grading proposed by ASTM D3515 [24] to be used in surfacing layer.

Fig. 1 illustrates the grading distribution for the three grading selected. AC 60/70 Asphalt from a local supplier was also used to prepare the mixtures. Furthermore, hydrated lime was utilized as an anti-stripping agent. Tables 1 and 2 list the properties of the siliceous aggregate source employed in this study. The physical properties of the asphalt are also presented in Table 3.

2.2. Preparation procedure

2.2.1. Mix design

The optimum asphalt content in the mixture was determined using ASTM D1559 [25]. According to this standard the optimum asphalt content is achieved when the stability and unit weight are in maxima and the air void becomes 4%. The resulting optimum asphalt content was checked for specification limits of the five standard parameters (stability, flow, air void, unit weight, and voids in mineral aggregate (VMA)). Under these conditions, the optimum asphalt contents were 6.1%, 5.6% and 5.4% for mixture with D1, D2 and D3 aggregate grades, respectively.

3. Experimental methods

3.1. Indirect tensile strength test

The aim of the modified Lottman Test (AASHTO T283) [26] is to evaluate susceptibility characteristics of the mixture to water damage. This test was performed by compacting specimens to an air void level of $7 \pm 1.0\%$. Three specimens were selected as dry (unconditioned) and tested without moisture conditioning; and three more were selected to be conditioned by saturating with water (70–80% saturation level). The specimens were tested for indirect tensile strength (ITS) by loading the specimens at a constant rate of 50 mm/min. Vertical deformation at 25 °C and the force required to break the specimen was measured. Moisture susceptibility of the compacted specimens was evaluated by tensile strength ratio (TSR) using the following equation:

$$\mathrm{TSR} = \frac{S_2}{S_1} \times 100 \qquad (1)$$

where S_1 is the average indirect tensile strength of dry (unconditioned) specimens and S_2 is the average indirect tensile strength of conditioned specimens. In this study, specimens were sorted into two subsets (both dry and conditioned) of three specimens each so that the average air voids (7%) of two subsets are equal.

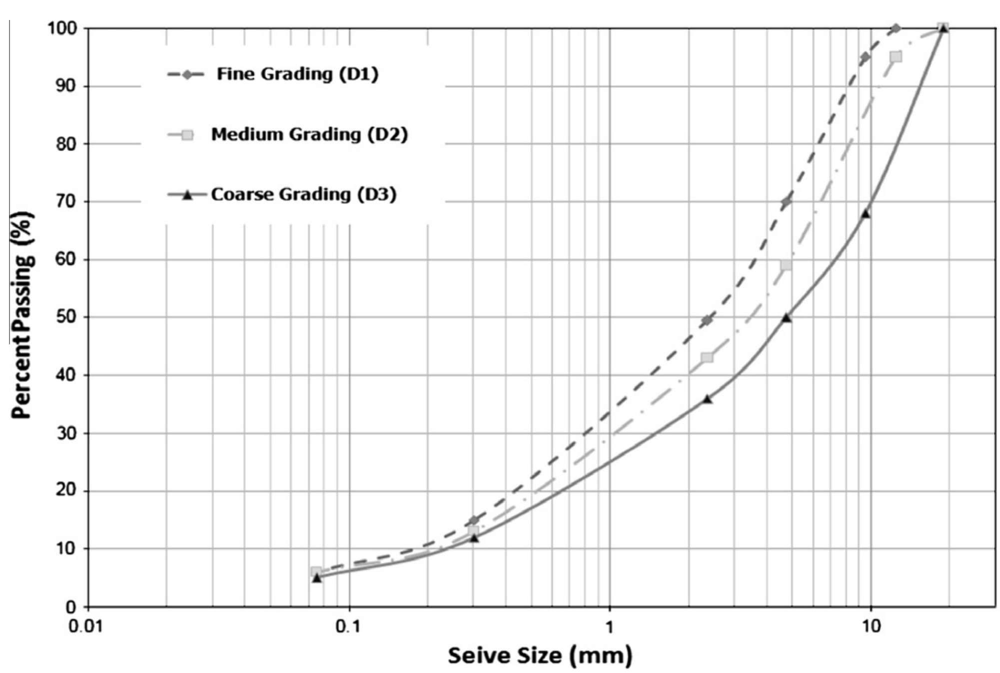

Fig. 1. Size distribution of the three aggregate grading selected.